Simulation Analysis to Utilize Hypolimnetic Withdrawal Technique for Eutrophication Control in Tropical Reservoir (Case Study: Jatiluhur Reservoir, Indonesia)

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Abstract

Reservoir is multipurpose infrastructure for water resource. However, the reservoir built in Indonesia generally has in eutrophication problems. To overcome these problems, the necessary technical measures are used such as using hypolimnetic withdrawal method. Therefore, the objective of this study is to make numerical simulation on the water quality dynamics model in reservoirs. The numerical model is to know the influence of hypolimnetic withdrawal technique for eutrophication control in Jatiluhur reservoirs. Water quality parameters simulated in this model are BOD, chlorophyll-a, total Nitrogen and total Phosphorus which generating eutrophication process. This study uses morphometric characteristics and water quality data taken from Jatiluhur Reservoir, as a case study. While, software used for simulation is WASP (Water Quality Analysis Simulation Program) created by US-EPA. Simulation analysis are performed in four scenarios: (1) the initial condition;(2) 50% pollutant load reduction; (3) 20 m^3/s hypolimnetic withdrawal application, and (4) the combination between 50% pollutant reduction and 20% hypolimnetic withdrawal application. Simulation results indicate that water quality improvement and eutrophication restoration has occurred at Jatiluhur reservoir using integration method i.e. 50% pollutant load reduction and applying the hypolimnetic withdrawal technique at least 20 m^3/s continuously.

Keywords

Eutrophication; Chlorophyl-a; WASP; Jatiluhur Reservoir; Hypolimnetic Withdrawal

Introduction

Background

Reservoir is multipurpose infrastructure for water resources mainly providing the raw water, flood control and environmental conservation. However, generally, the reservoirs built in Indonesia are in polluted condition and have been excessive fertilization or eutrophication status. More than 10 reservoirs in Java islands are in heavy pollution condition, resulting in eutrophic until hypereutrophic reservoirs [13].

The eutrophication process in reservoir ecosystem raises with the increasing of nutrients load entering to the reservoir and start from mesotrophic phase to eutrophic phase, and then increase to hypereutrophic phase. Eutrophication process, mostly due to the excessive nutrient substances in water reservoirs that are converted into inorganic nutrient substances, because of photosynthesis process. So, excessive growth mechanism of phytoplankton biomass occurs. Eutrophication condition in the reservoir causes a variety of problems, such as aesthetic mainly make worse the smell, transport disruption, low transparency, dissolved oxygen reduction, as well as the emergence of toxic substances [14].

Various technologies have been examined and applied for eutrophication control. Nevertheless, in general, these technologies need much energy and chemicals to reduce the chlorophyll concentration, which is the main indicator of eutrophication. As an alternative to control eutrophication problems is hydrodynamic application, such as hypolimnetic withdrawal technique [5]. Several reasons have support this technique, for instance: the water released from hypolimnion layer can reduce the excessive phosphorus concentration in reservoirs, therefore the eutrophication rate in reservoirs could be reduced [15]. Inflow and outflow arrangement in the reservoir could

also improve the quality of water, and then eutrophication problems in reservoir would be prevented [18]. Other reason explains that there is close relationship among the nutrients levels, dynamics of chlorophyll-a and the retention time of reservoir [6].

Based on the above concept, this study is intended to simulate and analyze the influence of hypolimnetic withdrawal technique for water quality improvements in the reservoir, mainly to overcome the eutrophication problems in tropical reservoirs, especially in Jatiluhur reservoir, Indonesia.

Factors Initiating Eutrophication Process

Factors initiating the eutrophication process are nutrients substances contaminating water bodies in suitable weather conditions for the phytoplankton growth and low flow velocities [17]. Other explanation also states that the important factors of eutrophication process in reservoir are: (1) the geometry of water body including depth, width, surface area and volume; (2) flow velocities and turbulence mixing; (3) the water temperature and sunlight intensity; (4) suspended solids content; (5) floating algae; (6) nutrients concentration, and (7) dissolved oxygen[7].

If the nitrogen concentration in water reservoir more than eight times of phosphorus concentration, then the eutrophication process is triggered by phosphorus (P) substances. In contrast, nitrogen (N) substances initiate the eutrophication process, if nitrogen concentration less than eight times of phosphorus concentration [17]. Knowing the ratio of N and P concentration is important to reduce specific nutrient affecting the eutrophication process in water bodies. Based on laboratory scale research using purely algae culture, it is shown that the excessive nutrients concentration are influenced by environmental factors, mainly sunlight intensity conducting very high of phytoplankton growth and making abundant concentration of phytoplankton [9]. The study also indicated that the optimum growth of Microcystis sp will occur at N and P ratio around 8 and the temperature is at 32^0 C. In such conditions, Microcystis sp can achieve the highest phase within the next two days [9].

Long-term model for eutrophication recovery

Eutrophication problems occur due to external and internal nutrient load. The external load caused by point source and non-point sources. While, internal load caused by pollutant sources within the water body including pollutant released by sediment layer that rich of nutrients. To recover the excessive algae concentration in reservoir, many efforts has been established. For example, water pollution from point sources can be restored by channels construction. Controlling the eutrophication problems caused by non point sources needs integration efforts namely domestic waste management, control of surface runoff pollution and artificial circulation and biomanipulation. Hipolimnion aeration, hypolimnetic withdrawal and dredging of sediment bottom are the efforts to reduce the internal pollutant load [5]. So, recovery and restoration efforts for eutrophication control require structurall measure, especially the reduction of nutrient loading in the reservoir [15].

In spite of this, behavior of biogeochemical response recovering the eutrophication problems in reservoir tends to slow and different on each of the reservoirs and other water bodies. Therefore, eutrophication control in reservoirs has to be done ultimately and should be integrated with nutrient load reduction as well as environmental improvement program on reservoir catchment [15].

Based on simulation using Eutro, part of WASP software, chlorophyll-a as an indicator shows that the eutrophication recovery in Lake Michigan could happen after 10 years through phosphorus and organics load reduction, that is chlorophyll-a concentration decline until 2.3-2.5 ug/L to 2-2.3 ug/L in the epilimnion. These explanations also describe that the eutrophication recovery program is slow response process, because 60% of phosphorus sediment are dissolves back into the water column. Then, eutrophication recovery program needs the sediment transport technology and herbicides to reduce of algae [16]. Consequently, the eutrophication recovery program should be done simultaneously and continuously through reduction of nutrients load, mainly nitrogen and phosphorus, in watersheds, stream, sediments bottom evacuation, as well as the environmental improvement in reservoir catchment [14].

The restoration programs of Lake Biwa, Japan, carried out continuously and integrated took almost 30 years since launched in 1999. Even, Shiga Prefecture (Japan) has built 9 large-capacity of domestic wastewater treatment plant, 11 water treatment system, 220 domestic wastewater treatment locally, so that Shiga Prefecture has served 83% of the domestic waste management systems. The results of recovery program is transparency of Lake Biwa increase 66,7 cm

after 29 years restoration or only reach 2.3 cm per year on average[4].

Hydrodynamics Influence on Eutrophication Process

In general, water in reservoir is stratified in three layers; those layers are epilimnion, metalimnion and hypolimnion. Hydrodynamic stream affects to the occurrence of reservoirs stratification, which tends to hinder the mixing process, especially on heat transfer process. The degree of reservoir stratification also depends on external influences, namely: wind diffusion, wave, process flow, internal inflow and outflow. In addition, the process of heating and cooling on the surface also involve in dynamics of stratification. Therefore, this phenomenon can trigger the eutrophication process, especially caused by mixing process among the layers [11].

Epilimnion is surface layer, no contact with sediment, warmer in temperature, and lower of retention period. Metalimnion is a layer between the epilimnion and hypolimnion. On this layer, there is a thermocline which limits the epilimnion and hypolimnion layer. Hypolimnion layer is a cooler layer, no contact with atmosphere and directly contact with the bottom sediment [2]. The mixing process is difficult happened, when metalimnion layer in reservoir is in sharp condition, so the accumulation of nutrient substances on the layers can occur on each layer. These circumstances cause phytoplankton accumulation in each layer. [11]

Hydrodynamics characteristics in the reservoir are very important in the mass transport process which can affect to other processes such as precipitation of pollutant substances. In addition, hydrodynamic currents influenced by wind and internal waves have an effect on the particle resuspension [1]. Based on two-dimensional model simulating the ecosystem on river-style reservoir shows that there are variations in the water quality vertically [10].

On large reservoirs, there is an effect of circulation current affected by wind, hydraulic flow, changes the water level, and turbulent diffusion that can be seen in Figure 1. These conditions affect to the pollutant transport that initiates on the eutrophication process. Consequently, software that consider to the hydrodynamic influence for pollutant transport and utilizing volume control approach is needed. WASP (Water quality Analysis Simulation Program) is the software to assess the eutrophication model in the reservoir that attention to the hydrodynamics and volume control approach [10].

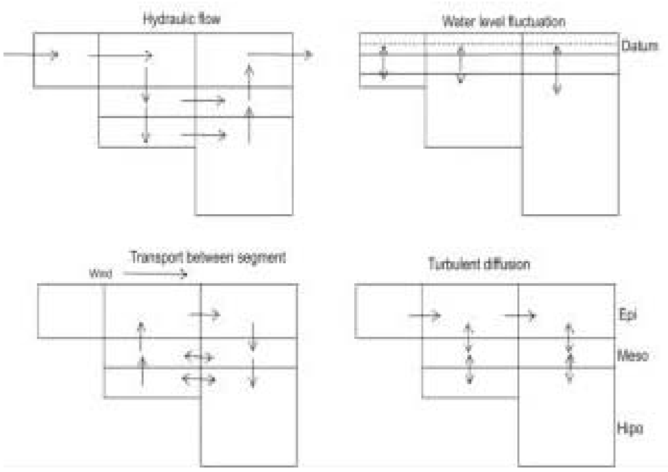


FIGURE 1 DIAGRAM OF CURRENT CIRCULATION AFFECTING THE POLLUTANT TRANSPORT PROCESS [10]

WASP Software

The software often used in the estimation of eutrophication is software WASP (Water quality Analysis Simulation Program)[2] . The software is produced by the US EPA as "public domain". The software is also used to forecast the quality of surface water such as lakes, reservoirs, and also rivers dynamic transport phenomena and changes in an environmental pollutant in water column and sediment layers are the principles of the WASP [19].

WASP is consisted of two sub programs that are EUTRO and TOXI. Sub program EUTRO is used to simulate and analyze for eutrophication process caused by nutrient substances and dissolved oxygen dynamics. Whereas, TOXI is utilized to estimate chemical contaminants concentrations including organic substances, heavy metals in surface water and sediments. The WASP simulation can perform a variety of problems look to the problems complexity and the number of parameters that are simulated as dissolved oxygen, BOD, nitrogen and phosphorus substances, and temperature and coli bacteria. Thus, the dynamics of the phytoplankton growth in a reservoir can be analyzed [19].

The basic equation of WASP software shown in **Eq.**1 to 3: [2]

$$\frac{\delta C}{\delta t} = \frac{\delta\left(A * D_x * \frac{\delta C}{\delta x}\right) y}{A * \delta x} - \frac{\delta(A * U_x * C)}{A * \delta x} + S_k + (S_b + S_L) \qquad (1)$$

accumulation dispersion advection internal reaction external source

which is:

C – pollutant concentration (g/m^3)

t – time (day)

A – flow area (m^2)

D_x – dispersion coefficient x direction (m/day)

x – distance x direction (m)

U – advection velocity x direction (m/day)

S_K– yield and lose of mass caused by internal reaction, calculated in volume segmen (g/m^3)

S_B – change of mass between segmen i and j caused by longitudinal dispersion, calculated in volume segmen[g/m^3 d].

S_B is defined as **Eq.2** as follows :

$$S_{Bi} = \frac{E_{t0}(t)*A_{t0}}{V_t*L_{t0}} * (C_A - C_B) \quad (2)$$

Where :

E_{i0}(t)–dispersion coeffisien as time function, at beginning i-segmen [m^3/day]

A_{i0} – surface area at beginning of –cross section [m^2]

Vi – volume of i-segment [m^3]

L_{i0} – Length of i-segment [m]

C_{jk} – Concentration of k-pollution indicator at j-segmen [g/m^3]

C_{ik} – Concentration of k-pollution indicator at i-segmen [g/m^3]

S_L – pollution load in an external flow, calculated for a water volume as **Eg.3**:

$$S_{Li} = \frac{1000*L_{ik(t)}}{V_t} \quad (3)$$

$L_{ik(kt)}$ – pollution load in external flow [kg/day]

Methods

Research Area

Jatiluhur reservoir is located at around 6^{0}33’29” S and 107^{0}18’25” E in West Java Province, Indonesia which has tropical climate. Jatiluhur reservoir, riverine and eutrophic reservoir, is used for research area that has 4500 km^2 of catchment area, while 8% of the catchment area are directly pollute to this reservoir, as seen at Figure 2[8].

Research is carried out with Jatiluhur reservoir data, because it has three outlets systems, namely: (1) water outlet in the surface or spillway; (2) the turbine intakes, and (3) the bottom outflow released by hollow jet gates. The capacity of reservoir is 2.44 billion m^3 at +107 asl (above see level), while average of inflow and outflow are 166 m^3/s and 161 m^3/s respectively. Nitrogen and Phosphorus pollutants load, released from feed fish-cage to the water body as internal pollutant load, is estimated 0.57 ton/day and 0.02 ton/day respectively. Nitrogen concentration in the inflow and outflow is 0.9 mg/l and 0.95 mg/L on average, respectively [8].

Figure 3 shows the main body of dam outlet that is spill way at +107 asl. Intake outlet to produce 187.5 MW of electricity is located at +61.7 and +75.9 asl. While, hollow jet gates required to increase the downstream capacity is positioned at +49 asl. Consequently, both of the gates are situated in the hypolimnion layer on Jatiluhur reservoir. The hypolimnetic withdrawal technique in this study uses hollow jet gates to discharge the hypolimnion layer, in order to improve water quality and then eutrophication process in epilimnion layer can be reduced ***Simulation method***

The parameters that will be simulated in this research are organics as BOD, Total Nitrogen (TN), Total Phosphorus (TP) and Chlorophyll-a. This research starts with the data collection i.e. bathymetric map, pollutant load entering to the water body. This data becomes input to WASP software that uses box volume model. Figure 4 shows the flow diagram of research methodology. While, coefficient and criteria used for the input to WASP software can be seen at Table 1.

The simulation is performed by four scenarios, namely: (a) the existing or initial condition; (b) the reduction of pollution load both external and internal; (c) the existing condition with hipolimnetic withdrawal technique; and (d) integration between pollution loads reduction and hypolimnetic withdrawal technique. Simulation object is in epilimnion layer where the eutrophication process occurs caused by photosyntetic process. The segments 1 are chosen as main pollutant load input, while segment 5 are simulated representing the riverine zone. Segments 7 and 9 analyzed represent the transition and lacustrine zones respectively.

TABLE 1 CRITERIA AND COEFIESIENT TO ANALYZE EUTROPHICATION MODEL BY WASP [19]

Description	Notation	Value	Units
A. Physical criteria			
Light extinction coefficient	K_e	0.1-0.5	per meter
Depth of segmen	D	0-40	meter
Water temperature	T	0-35	^oC
Light day fraction	F	0.3-0.7	
Mean of sun radiation on the surface water	I_a	200-750	Langley/day
Population rate constanta of zooplankton	Z	0	mg C/L
Maximum growth rate of Zooplankton	Klc	2	per day
Maximum light absorbtion of photosintesis	Ömax	720	mg C/mol foton
Saturated light intensity	I_s	200-500	Langley/day
Light absorbtion of Phytoplankton	K_e	0.017	m^2/mg Chlorofil-a
Setling transport simulation :			
- CBOD and NBOD	Solid-3		
- Organic N and Organic P	Solid-1		
- Phytoplankton	Solid-2		
- PO_4	Solid-3		
- Particulate BOD	Solid-1		
- Advection flow	Solid-1		
Density solid-1		2.65	g/m^3
Density solid-2		2.63	g/m^3
Density solid-3		1,35	g/m^3
Water column density		1.0	g/m^3
Critical shear velocity	V_i	11-22	cm/s
Setling velocity	V_s	0.1	m/day
Diffusion exchange coeffisien	E_{di}	2e-4	m^2/day
Bentos depth layer	D_i	0.2-0.7	meter
Wind velocity (1. Lab scale;2.Lake;3.Ocean)		2 (lake)	
Fraction of reaeration area		1 (total area)	
Equivalen of roughness		0.25-0.35	
B. Criteria of biochemical reaction rate			
Endogen respiration at 20^0C	K_{1R}	0.02-1.045 (0.125)	per day
Carbon:chlorofil-a ratio	C_e	20-50	
Carbon: Oxygen ratio	A_{OC}	32/12	mg O_2/mg C
Phytoplankton N-C ratio	A_{NC}	0.25	mg N/mg C
Deoksigenation rate coeffisien at 20^0C	K_d	0.21-1.6 (1.047)	mg O_2/L
Oxygen half saturation constant	k_{BOD}	0.5	
Nitrogen half saturation constant	K_{mN}	25	mg N/L
Phosphorous half saturation constant	K_{mP}	1	mg P/L
Phytoplankton settling velocity		0.07-18	m/hari
Nitrification rate at 20^0C	k_{12}	0.09-0.13	mg N/L
Denifitrication rate at 20^0C	K_{2D}	0.09	per day
Mineralisation rate of nitrogen organic at 20^0C	K_{71}	0.075	per day
Phytoplankton growth rate	G_{PL}	0.1-0.5	per day
Phytoplankton death rate	K_{1D}	0.02	per day
Phytoplankton respiration rate at 20^0C	Kir	0.125	per day
Reaeration fraction of SOD	SOD	0.2-4 (1.028)	per day
Grazing rate of zooplankton		0.1-1.5	L/mg C-day
CBOD dissolved Fraction	f-BOD_5	0.5	
Organic carbon (CBOD) decomposition rate	Kds	0.0004	per day
Phosfor organic decomposition rate	K_{oPD}	0.0004	per day
Inorganic fraction of dissolved phosphorous on benthic layer	f_{DJ}	0.045-0.001	

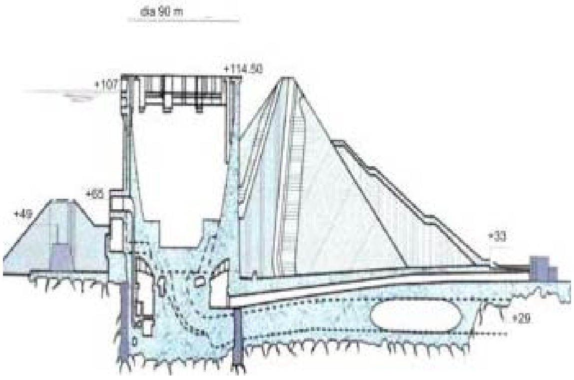


FIGURE 2 DAM BODY AND OUTLETS SYSTEM AT JATILUHUR RESERVOIR [7]

FIGURE 3 JATILUHUR RESERVOIR AS A RESEARCH AREA [12]

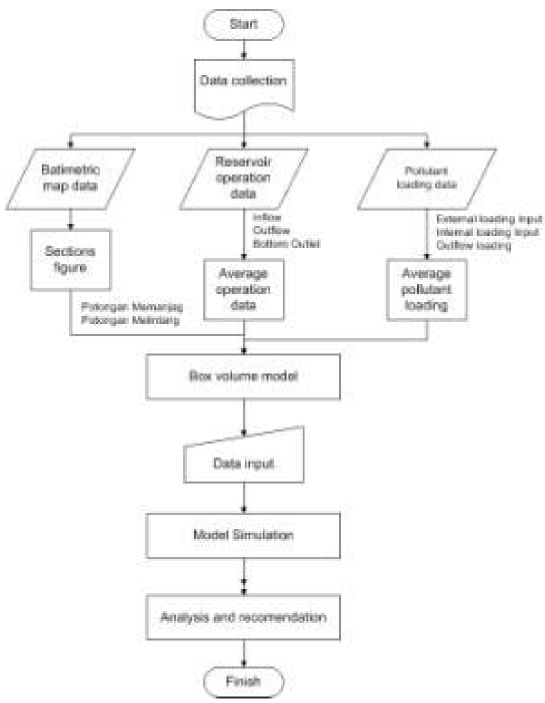


FIGURE 4 FLOW DIAGRAM OF STUDY METHODOLOGY

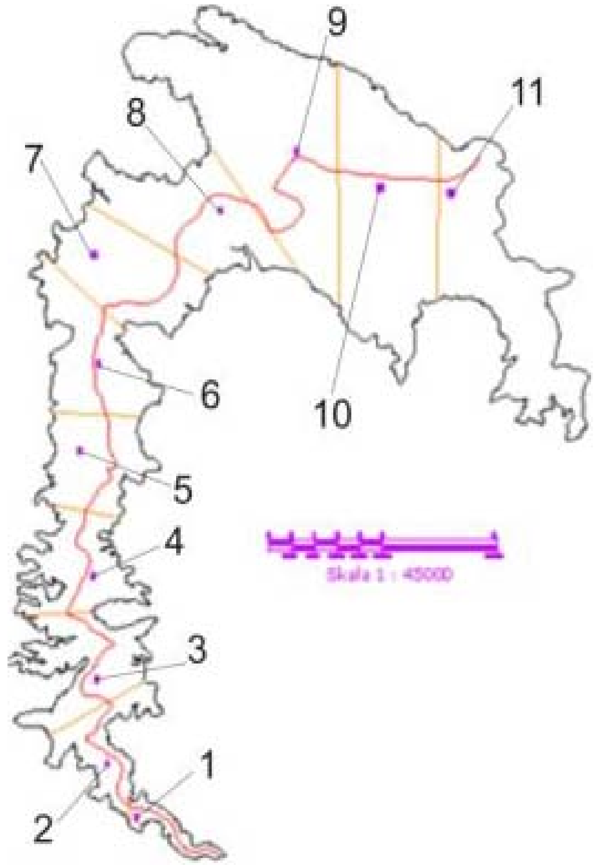


FIGURE 5 SEGMENTS MODEL FOR JATILUHUR RESERVOIR

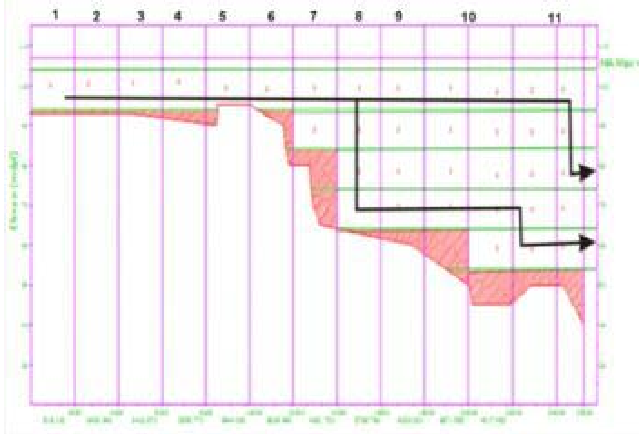


FIGURE 6 BOX VOLUME MODEL ESTABLISHED BY JATILUHUR BATIMETRIC MAP

Results and Discussion

Simulation Results

1) Simulation on intial condition

Figure 7 indicates that the concentrations of the parameters of BOD and chlorophyll-a concentration decreases in the flow direction from the upstream to the downstream of the resevoir, whereas the TN and TP have relatively uniform concentrations along the

reservoir. Existing conditions on water quality in Jatiluhur reservoirs are organics substance between 5.5 to 7 mg/L as BOD on location 1 and 5, range concentrations of chlorophyll-a are 0.002 to 0.005 mg/m^3, TN: 0.4-0.8 mg/L, whereas the TP: 0.1-0.32 mg/L.

2) Simulation on the affect of pollutant load reduction

Figure 8 shows simulation results when the pollutant load is reduced until 50% both internal and external pollutant load. Simulation results show that pollutants concentrations in the reservoirs tend to decline. Organic substance concentration tend to decrease until 2 to 3.5 mg/L BOD, chlorophyll-a concentrations are reduced to 0.001-0.0025 mg/m^3, the concentration of TN in overall locations decreases to 0.2-0.5 mg/L, whereas the TP concentration reduces to

0.12-0.016 mg/L.

3) Simulation on the affect of hypolimnetic withdrawal technique

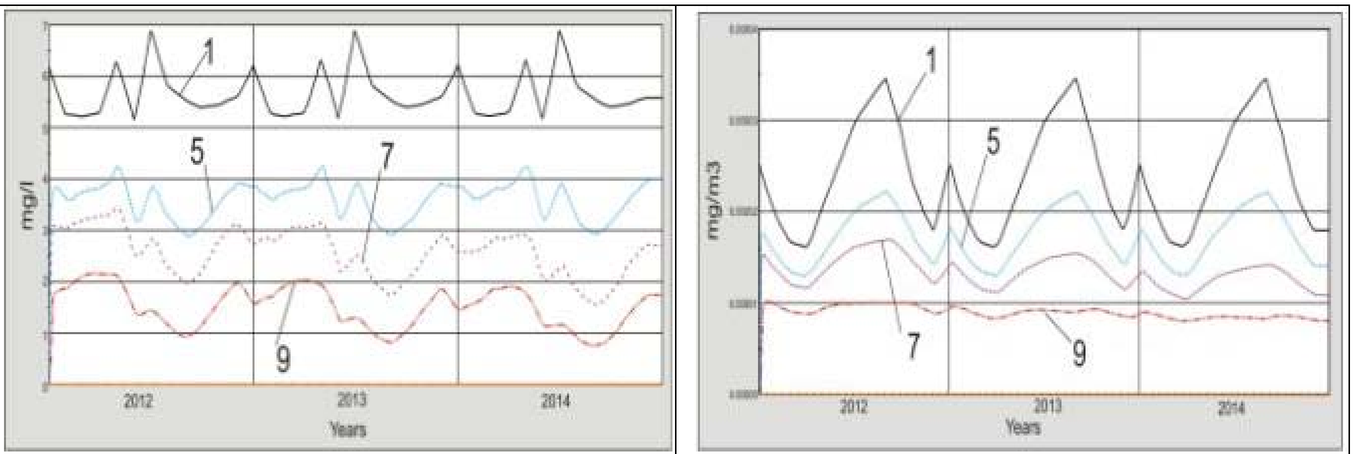
Figure 9 illustrates the influence of hypolimnetic withdrawal through the hollow jet gates to the water quality parameters, mainly eutrophication parameters. The simulation results show that pollutants concentrations in zones 1 and 5, located in riverine zone, indicate not change. While, the pollutans concentration tend to decrease from time to time at zone 7, located in transition zone, and zone 9 (in lacustrine zone). Organics concentrations decreased to 0.5 to 3.5 mg/L

BOD, chlorophyll-a concentrations are declined to 0.0004-0.0012 mg/m^3. While TN and TP concentrations at zones 7 and 9 indicate also to be decreased eventually. Range of TN concentration is 0.2-0.5 mg/L, whereas the TP concentrations decrease to 0.01-0.025 mg/L.

4) Simulation on the simultant effect of pollutant load reduction and hypolimnetic withdrawal

Figure 10 illustrates the combination effect of pollutant load reduction and hypolimnetic withdrawal technique with capacity of 20 m^3/s. The simulation results show that the pollutants concentration in the overall location decrease almost 50%. Conversely, at zone 7 (transition zone) and zone 9 (lacustrine zone) tend to decline in two years simulation. Declining of pollutants concentrations at zone 7 and 9 indicate that the hypolimnetic withdrawal technique has affect to the water quality improvements at zone 7 to 9.

Based on the simulations, organics concentrations tend to decrease until 0.5 to 1.5 mg/L of BOD, chlorophyll-a concentrations are reduced to less than 0.0002 mg/m^3. Concentrations of TN and TP are decreased to 0.2-0.3 mg/L and 0.01-0.016 mg/L respectively. These concentrations resulted from the simulations shows that eutrophication problems in Jatiluhur reservoir can be reduced through the simultant action, that is reduce the pollutants load both external and internal load and applying the hypolimnetic withdrawal technique.



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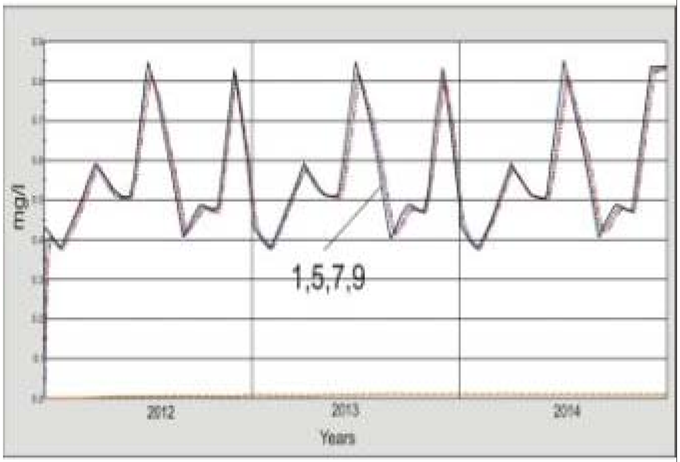

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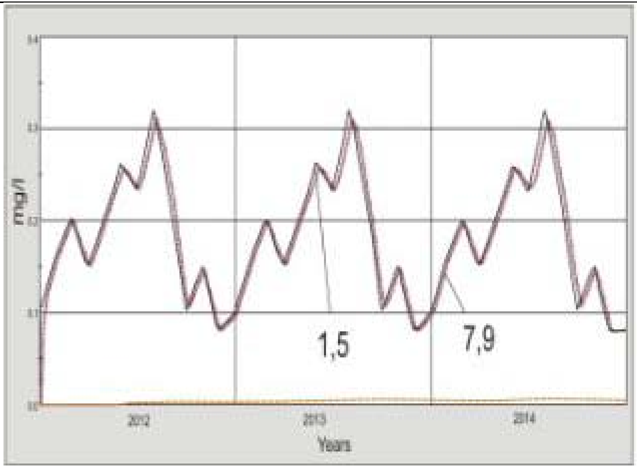
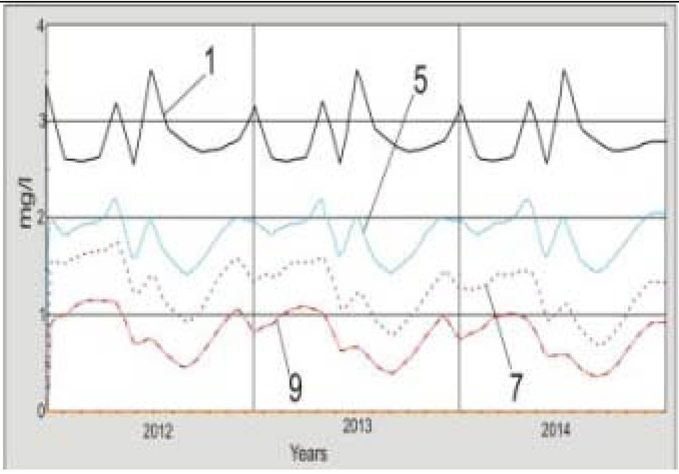


(d)

FIGURE 7 WATER QUALITY SIMULATION ON INITIAL CONDITION: (A) BOD; (B) CHLOROFIL-A; (C) TN, AND (D) TP



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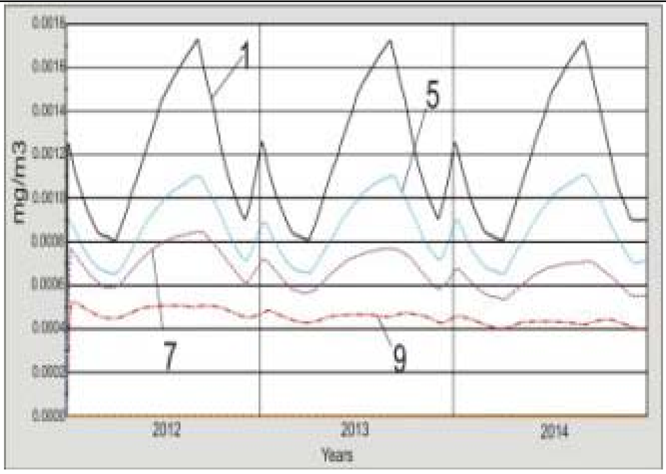

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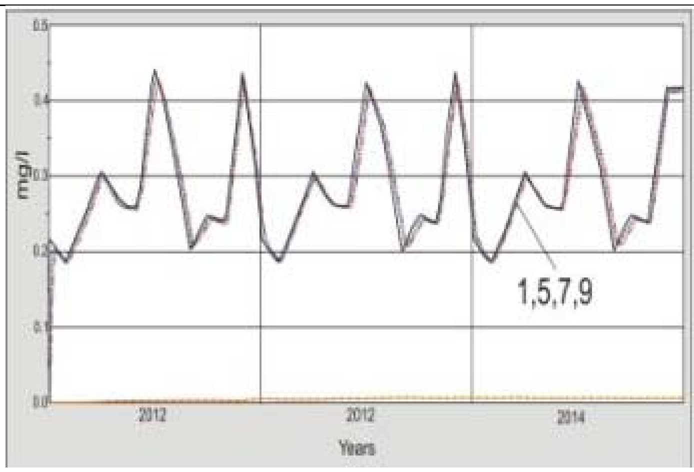

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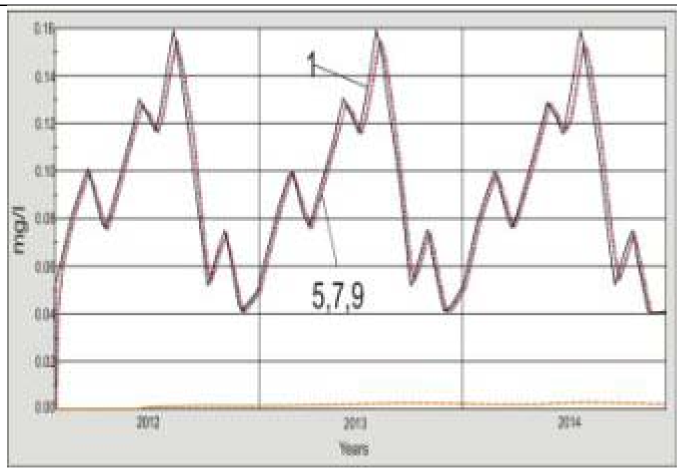
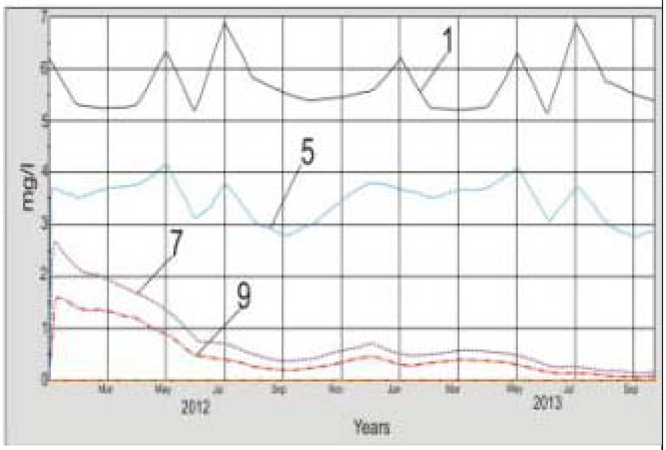


(d)

FIGURE 8 WATER QUALITY SIMULATION BY 50% REDUCTION OF POLLUTANT LOADING: (A) BOD; (B) CHLOROFIL-A; (C) TN, AND (D) TP



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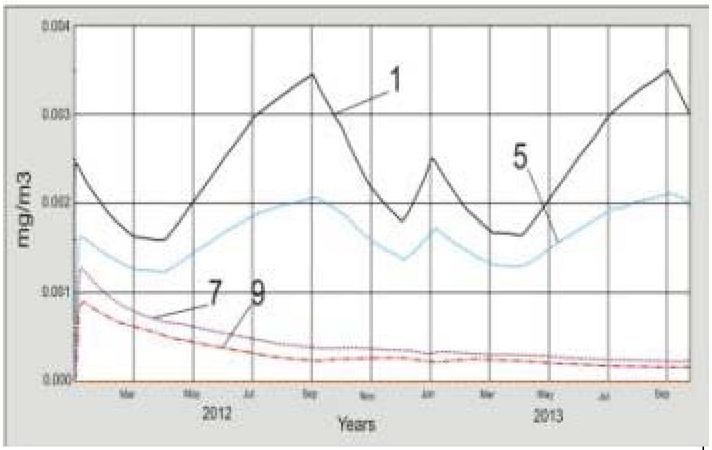

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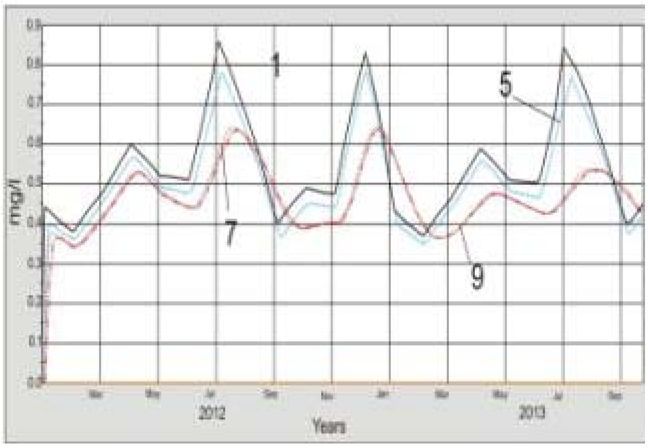

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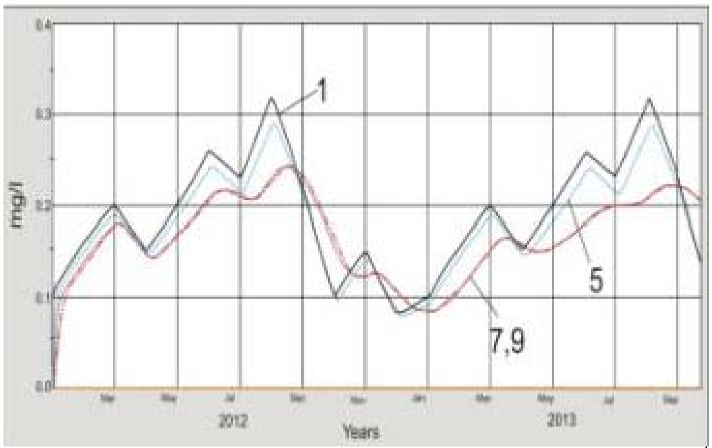
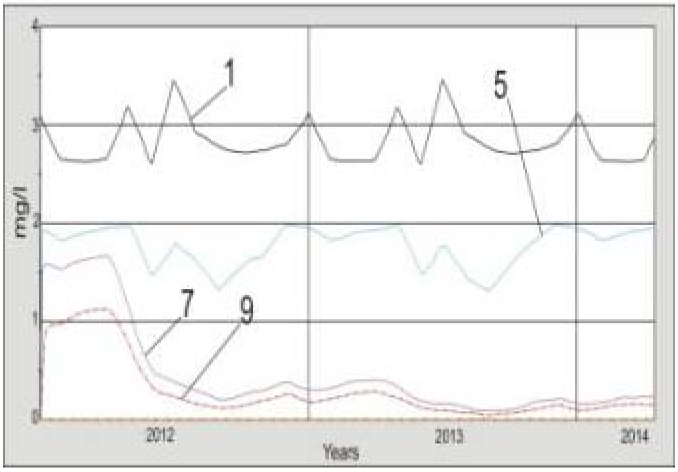


(d)

FIGURE 9 WATER QUALITY SIMULATION RELEASE 20M³/S OF HYPOLIMNETIC WITHDRAWAL: (A) BOD; (B) CHLOROFIL-A; (C) TN, AND (D) TP



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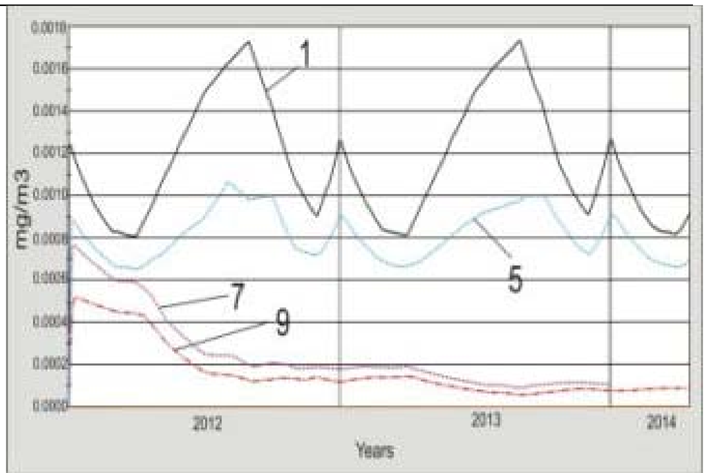

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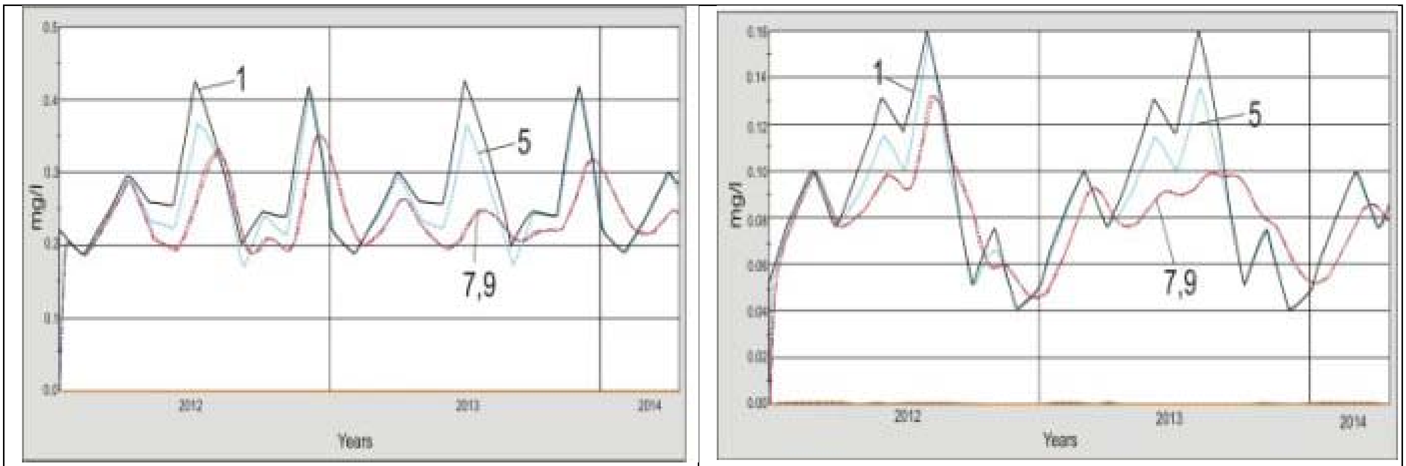

(c) (d)

FIGURE 10 WATER QUALITY SIMULATION ON 50% REDUCTION OF POLLUTAN LOAD AND RELEASE OF 20 M^3/S HYPOLIMNETIC WITHDRAWAL: (A) BOD; (B) CHLOROFIL-A; (C) TN, AND (D) TP

Implication to Water Quality Management

Hypolimnetic withdrawal can be an alternative technique and good prospect for eutrophication control in tropical reservoir, because the method is low cost to decrease internal loading of nutrients. In tropical country, such like Indonesia, hypolimnetic withdrawal is normally discharged for power generation, irrigation and for other needs of raw water. Then, this technique is also available for nutrients export and also enhance the supply of irrigation water released by hollow jet gates.

Nevertheless, based on the simulation analysis, the application of hypolimnetic withdrawal technique only affect to lacustrine and transition on Jatiluhur reservoir. This technique is necessary to develop for application in large reservoir, in order to avoid the eutrophication process in overall zones on the reservoir. So, this technique would not only applicable to small reservoir.

Besides that, discharge of hypolimnetic water containing high concentration of Phosphorous, ammonia, H_2S, reduced metals, and no oxygen may cause a water quality problem in downstream. With the intention that there is an improvement system on water quality along the stream that the water bodies containing hypolimnetic water discharged through hollow jet gates. Therefore, to improve the stream quality that has polluted by hypolimnetic water, cascade aeration along the stream should be applied to reduce ammonia, H_2S, increase of DO and P precipitation.

Removing hypolimnetic water reduces the residence time of hypolimnion and then lessens to the period of anoxic layer. This condition can minimize the transport of hypolimnetic nutrients and avoid anoxic water to the epilimnion. Hypolimnetic withdrawal can diminish stratification in reservoir; because epilimnetic water tends to be downward making destratification will not occur. Thus, the eutrophication process in epilimnetic layer could be reduced [4].

The influence of hypolimnetic withdrawal on the reduction of nutriens hypolimnetic is direct effect, while the affect on epilimnetic nutrients reduction are indirect effect showing that the nutrients from hypolimnion to epilimnion is declined. Nutrients in epilimnion layer are principally as a function of TN and TP transported over the withdrawal technique used. The longer withdrawal operated the greater is the proportional change in epilimnetic nutrients. However, the reduction in anoxic layer could not correlate with withdrawal rate [5]. Therefore, the reduction of anoxic layer with hypolimnetic withdrawal technique is not physically powerful.

Combination between reduction of nutrient load, originated from external and internal load, and hypolimnetic withdrawal technique should be carried out continually, because sustained nutrient export should optimally reduce the nutrient, particularly P both in water column and sediment layer. Therefore, application of hypolimnetic withdrawal technique would be more effective for eutrophication control, mainly in Jatiluhur reservoir, pollution control program surrounding the reservoir catchment should be intense.

Conclusions

Knowing the influence of reservoir operation, particularly the bottom outlet operation to the dynamics of reservoir eutrophication, then efforts for eutrophication control can be performed to integrate the hypolimnetic withdrawal technique in the operation of Jatiluhur reservoir, in order to improve the water quality.

Simulation results indicate that reduction of pollutant load both external and internal can improve water quality in the reservoir. Whereas, the application of hypolimnetic withdrawal technique can also reduce the water quality parameters, especially the parameters which can initiate the eutrophication process on transition and lacustrine zones in Jatiluhur reservoirs.

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